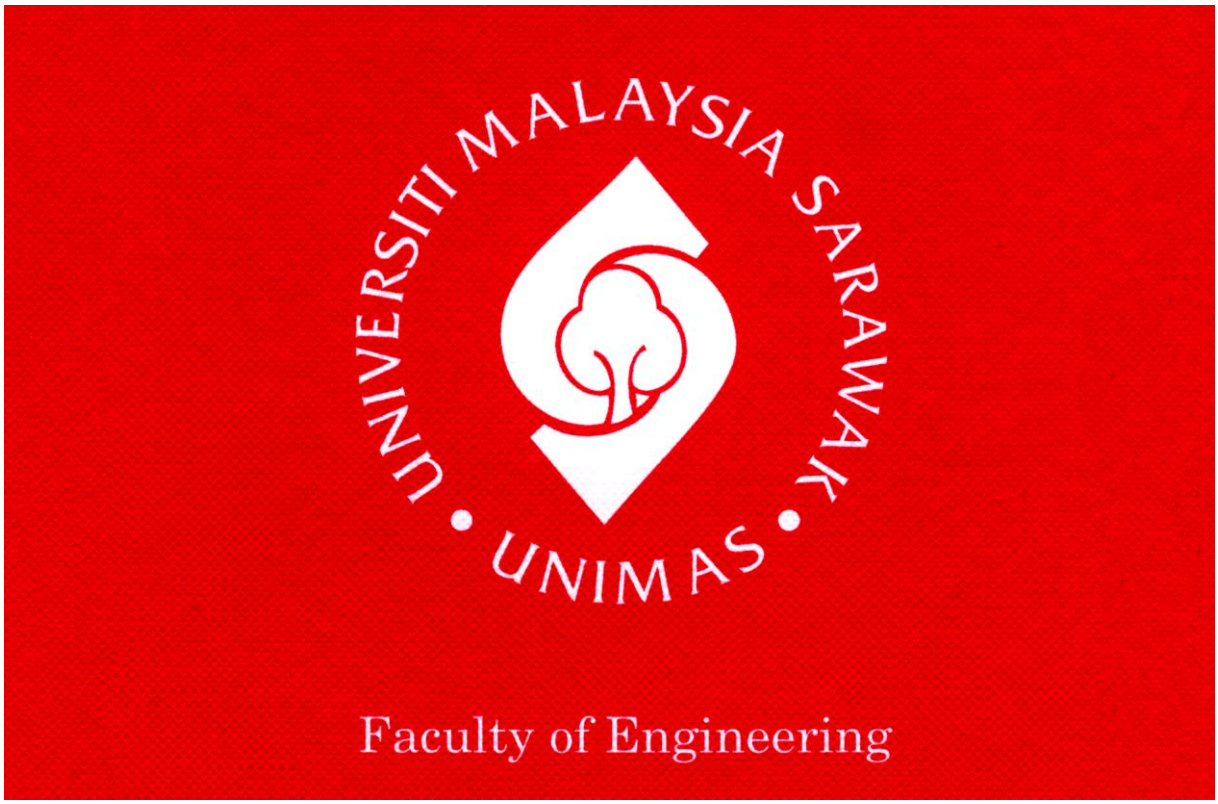

MODELING AND CONTROLLER DESIGN OF A BALL AND BEAM SYSTEM

Chua Chong Liang

Bachelor of Engineering with Honours

(Electronic and Computer Engineering)

2009

UNIVERSITI MALAYSIA SARAWAK

R13a

BORANG PENGESAHAN STATUS TESIS

Judul: **MODELING AND CONTROLLER DESIGN OF A BALL AND BEAM SYSTEM**

SESI PENGAJIAN: 2008/2009

Saya **CHUA CHONG LIANG**
(HURUF BESAR)

mengaku membenarkan tesis * ini disimpan di Pusat Khidmat Maklumat Akademik, Universiti Malaysia Sarawak dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Sarawak.
2. Pusat Khidmat Maklumat Akademik, Universiti Malaysia Sarawak dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Membuat pendigitan untuk membangunkan Pangkalan Data Kandungan Tempatan.
4. Pusat Khidmat Maklumat Akademik, Universiti Malaysia Sarawak dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
5. ** Sila tandakan (✔) di kotak yang berkenaan

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972).

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/ badan di mana penyelidikan dijalankan).

☑ TIDAK TERHAD

Disahkan oleh

(TANDATANGAN PENULIS) (TANDATANGAN PENYELIA)

Alamat tetap: NO.11, CHABANG EMPAT
TENDONG, 17030 PASIR MAS,
KELANTAN

MS. MAIMUN BINTI HUJA HUSIN
Nama Penyelia

Tarikh: Tarikh:

CATATAN
***** Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah, Sarjana dan Sarjana Muda.
****** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT dan TERHAD.

UNIMAS/15/02/2009

22 May 2009

Pustakawan

Pusat Khimat Maklumat Akademik

Universiti Malaysia Sarawak

Puan,

Laporan Projek Tahun Akhir

Laporan pelajar ini adalah dikategorikan sebagai “terhad” selama 2 tahun. Ini adalah kerana maklumat yang terkandung merupakan maklumat sebenar jabatan kerajaan di mana kajian dibuat.

Sekian, terima kasih.

“BERKHIMAT UNTUK NEGARA”

Yang benar,

Dr. Wan Azlan Bin Wan Zainal Abidin

Ketua Jabatan

Kejuruteraan Elektronik

b.p. Dekan, Fakulti Kejuruteraan

This Final Year Project attached here:

Title : Modeling and Controller Design of a Ball and Beam System

Student Name : Chua Chong Liang

Matric No : 13907

has been read and approved by:

_____ _____

Ms. Maimun Binti Huja Husin Date

(Supervisor)

MODELING AND CONTROLLER DESIGN OF A BALL AND BEAM SYSTEM

CHUA CHONG LIANG

This project is submitted in partial fulfillment of
The requirements for the degree of Bachelor of Engineering with Honours
(Electronics and Computer Engineering)

Faculty of Engineering
UNIVERSITI MALAYSIA SARAWAK
2008/2009

Dedicated to my beloved family and friends.

ACKNOWLEDGEMENT

This project has been made possible as a result of the co-operation and support rendered by several individuals. While it is impossible to list down all of them, I am very grateful for their assistance.

Firstly, I would like to thank to my supportive supervisor, Ms. Maimun Binti Huja Husin. Her patience, advices, comments and guidance has helped me throughout the course our project.

Next, I would like to thank to my family and friends for all their support and companion that had helped me in sailing through the hard days in lives and studies all these while.

Finally, I would like to express my gratefulness to the individuals who involved direct or indirectly during the progress of this project.

ABSTRAK

Ball and beam system boleh didapati di kebanyakan makmal kawalan universiti. Ia adalah salah satu model makmal yang terkenal bagi sistem kawalan. Sistem ini terdiri daripada bebola, alur, motor arus terus dan beberapa alat penderia. *Ball and beam system* terbahagi kepada dua tatarajah yang mana alur disokong di tengah dan alur disokong di kedua-dua belah. Bebola bergelek di atas alur secara bebas. Ini menyebabkan sistem menjadi gelung terbuka, tidak stabil dan tidak lelurus. Model matematik bagi *ball and beam system* adalah tidak lelurus secara semulajadi tetapi mungkin dileluruskan sekitar kawasan mendatar. Walaubagaimanapun, model yang telah dileluruskan masih mewakili kebanyakan sistem nyata seperti penstabilan mendatar bagi sebuah kapal terbang semasa mendarat dan di dalam aliran udara yang bergelora. Terdapat banyak kaedah kawalan yang boleh digunakan pada masalah sistem ini. Di dalam projek ini, kaedah kawalan *PID* dan *State Space* digunakan untuk menyelesaikan masalah ini. Keputusan prestasi optimum yang diperolehi dari kaedah kawalan *PID* dan *State Space* dibandingkan.

ABSTRACT

Ball and beam system can be found in most university control labs. It is one of the most popular laboratory models for control system. The system consists of ball, beam, DC motor and several sensors. There are two configurations of ball and beam system which is the beam is support in the middle and both side. The ball is rolls on the beam freely. This cause the system becomes open loop, unstable and nonlinear. The mathematical model for ball and beam system is inherently nonlinear but may be linearized around the horizontal region. This simplified linearized model, however, still represents many typical real systems, such as horizontally stabilizing an airplane during landing and in turbulent airflow. Many control methods can be applied to this system problem. In this project, PID and State Space control methods are used to solve this problem. The optimum performance result obtained from PID and State Space control methods are compared.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AC	-	Alternative Current
A/D	-	Analog to Digital
d	-	Lever arm offset
DC	-	Direct Current
DSP	-	Digital Signal Processing
g	-	Gravitational acceleration
GND	-	Ground earth
J	-	Ball's moment of inertia
k	-	Constant
L	-	Length of the beam
LQG	-	Linear Quadratic Gaussian
LQR	-	Linear Quadratic Regulator
M	-	Mass of the ball
MATLAB	-	Matrix Laboratory
MIMO	-	Multiple Inputs Multiple Outputs
MRAC	-	Model Reference Adaptive Control
PD	-	Proportional Derivative
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative

R	-	Radius of the ball
r	-	Ball position coordinate
α	-	Beam angle
θ	-	Motor angle
Ω	-	Ohm
F_{rx}	-	Force due to ball rotation
F_{tx}	-	Force due to translational motion
K_D	-	Derivative gain
K_I	-	Integral gain
K_P	-	Proportional gain
T_D	-	Derivative time
T_I	-	Integral time
V_{source}	-	Voltage source

CHAPTER 1

INTRODUCTION

1.1 Ball and Beam System

The ball and beam system is also called ‘balancing a ball on a beam’. It is one of the most popular and widely used laboratory models for control systems. It is simple to understand as a system and the control techniques are cover many important classical and modern design methods. Figure 1.1 is illustrating the ball and beam system.

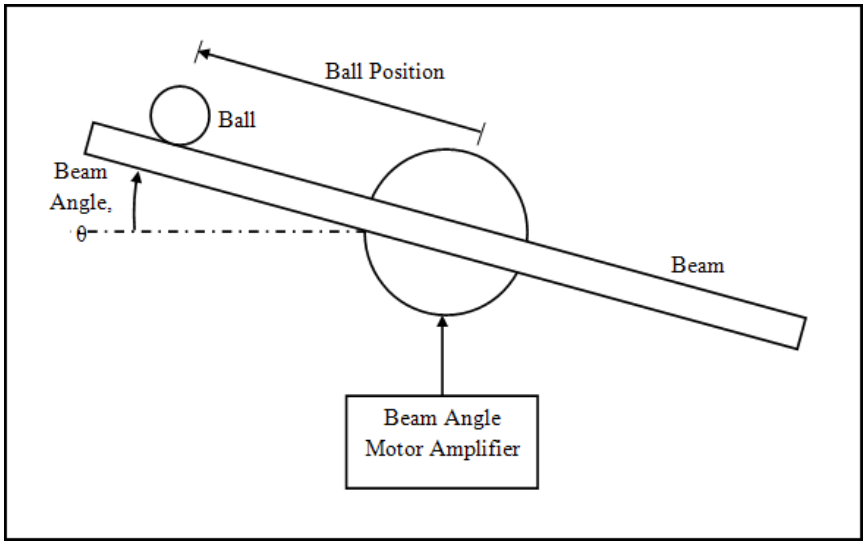

Figure 1.1: Ball and Beam System Diagram (Wellstead, 2008)

Generally, the ball and beam system is connected to real control problem such as horizontally stabilizing an airplane during landing and in turbulent airflow. There are two degrees of freedom in this system. First is the ball rolling up and down on the beam and second is the beam rotating through its centre axis. The main purpose of the system is to control the position of the ball along the beam to a desired position by manipulating the angular position of the DC motor. The position of the ball on the beam can be measured using a special sensor. The control voltage signal is send to the DC motor through a power amplifier and then the torque generated by the motor drive the beam to rotate to the desired angle. Thus, the ball can be located at the desired position.

The ball and beam system is open loop and important to point out that it is unstable and nonlinear because the ball position changes with acceleration without limit for a fixed beam angle. Unlike the linear dynamic systems, nonlinear systems

often possess structural properties that make them very difficult to control (Wellstead, 2008).

The unstable problem of the system can be solved by closing the open loop with a feedback controller. There are many types of feedback control can be used to stabilize the system such as Proportional Integral Derivative (PID) Control, State Space Method Control and Model Reference Adaptive Control (MRAC). The nonlinear property is not significant when the beam only deflects a small angle from the horizontal position (Wei, 2007).

1.2 Problem Statement

Most control problems that can meet in practical world are straightforward to control. For a fixed input signal produce more or less constant of output. Unstable and feedback control is to make the operation operate safely. Many modern industrial processes and technological system as such unstable could be used without stabilizing feedback control (Wellstead, 2008). One important practical example of unstable systems is the control of an aircraft during vertical take-off or during landing and in turbulent airflow. The angle of thruster's jets is needed to control continually to prevent the aircraft tipping. So feedback control is required.

1.3 Objectives

The objectives of this project are listed in the following:

i. To obtain a mathematical model of the ball and beam system.

ii. To design two controllers to control and stabilize the nonlinear ball and beam system.

iii. To design a Simulation control model of the system using MATLAB software.

iv. To compare the two controllers in settling time less then 3 seconds and overshoot less then 5%.

v. To compare four basic algorithm of PID controller.

1.4 Scope of the Project

The purpose of this project is to design two controllers as a feedback control to control and stabilize the unstable ball and beam system. The ball and beam system is often used as a bench mark problem for many different control systems. The ball rolling freedoms on the beam with acceleration make it become unstable. The system is represented in mathematical model. In this project, the control task is to stabilize the system. Two controllers have been chosen to perform this task, which are PID Controller and State Space Controller. MATLAB software is used as the software simulation for the unstable ball and beam system model and the two controllers that have been chosen to solve the system problem.

1.5 Project Outline

This Final Year Project's Report consists of five chapters. The brief information of each chapter is described as below:

Chapter 1: Introduction

This chapter provides a brief introduction of ball and beam system and it operation. The problem statement, objectives and the scope of the project are outlined as well. Besides that, project outline is also provided in this chapter.

Chapter 2: Literature Review

This chapter reviews some literature on the ball and beam system and the controllers that can be used to solve the system problem. Five controllers are listed out in this chapter, which are PID Control, State Space Control, MRAC, Fuzzy Control and Neural-Network Predictive Control.

Chapter 3: Methodology

This chapter explains how the project is able to complement the problem stated and expected problem during project. It also provides the information of the methods used in the project. Start with describing the theoretical prediction methodology that is mathematical model for ball and beam system. It also presents the PID Control and State Space Control design implementation.